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A 4-MJ Mobile Pulse Power Facility for Electrothermal-Chemical (ETC) Gun Applications

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13. ABSTRACT *(Maximum 200 words)*

In support of advanced electric gun research in progress within the U.S. Army, a mobile pulsed power system has been developed and made operational as part of the U.S. Army Research Laboratory (ARL) electric gun research facility. This mobile system has a maximum energy storage capability of 4 MJ, and it can deliver gigawatt levels of pulsed power over time periods of several milliseconds. The configuration of the system is that of a pulse-forming network (PFN) that is comprised of a bank of 80 high-energy capacitors, pulse-shaping inductors, switches and other electronic components which are designed to provide a variety of pulsed power profiles for electric propulsion research. The prime power for the PFN consists of a 1-MW diesel generator interconnected with a 27-kV constant voltage power supply. The system is controlled and monitored with electronic instrumentation from a remote control station which makes use of optical fiber signal transmission techniques. Recently acquired experimental pulsed power data from the facility are presented and discussed.

14. SUBJECT TERMS
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1. BACKGROUND AND EXPERIMENTAL

1.1 Pulse Forming Network Characteristics. The Pulse Forming Network (PFN) design for this electric gun facility was selected mainly on pulsed output-power versatility. As a result, a type C network was selected which consists of multiple inductor-capacitor (LC) circuits or submodules each having its own output closing switch. This configuration is considered a "voltage-fed" network, which stores energy initially in the form of an electrostatic field on capacitor plates. The electrical energy is released in the form of output current flow to a load impedance.[1] The main power components used in the system include capacitors, inductors, rectifiers, and high-power switches, which are shown schematically in the diagram, Figure 1. Versatile pulse shaping is obtained by adjustments in the temporal delay of the output switches. This feature has been demonstrated both experimentally and through the use of electronic circuit simulations for this particular power system and it will be discussed further in the report.

Initial work on the PFN design was performed by Maxwell Laboratories Inc., San Diego, CA, with technical input and requirements provided by the U.S. Army, the details of which have been published elsewhere.[2,3] PFN design, systems validation, testing, and technical consultation were also performed by Vitronics Inc., Eatontown, NJ, through contract no. DAAL01-92-C-0265 during the period March 1993 through April 1995. The completed pulsed power supply consists of 10 PFN submodules and a total of 80, 50-kJ, type C, energy storage capacitors (Maxwell model 32511). Each capacitor has an energy density of 0.66 J/g, maximum charging voltage of 24 kV, and internal capacitance of 175 µF.

Other power components include pulse shaping inductors, high-power rectifiers, and spark-gap closing switches. The system operates as 2 separate modulators each with 40 of the previously mentioned capacitors. Each modulator contains five banks of eight parallel connected capacitors, which together store a total of 2 MJ of electrical energy. The stored energy is delivered from all submodules to a common output load, e.g., an electric gun. Each of the 10 submodules is directly connected to a pulse-shaping inductor and output sparkgap closing switch. Power rectifiers at the end of each submodule line are used

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[1] Glasoe, G. N., and J. V. Lebacqz. Pulse Generators. New York: McGraw-Hill, Inc. 1948.

[2] Pastore, R., T. Podlesak, and H. Singh. Progress in 2N Megajoule Electrothermal-Chemical Gun Pulser." Proceedings of the 9th IEEE International Pulsed Power Conference, pp. 783–786, 1993.

[3] Rinehart, H., et al. "A 6.6-MJ Modulator for Electrothermal-Chemical Guns." Proceedings of the 19th Power Modulator Symposium, pp. 499–502, 1990.

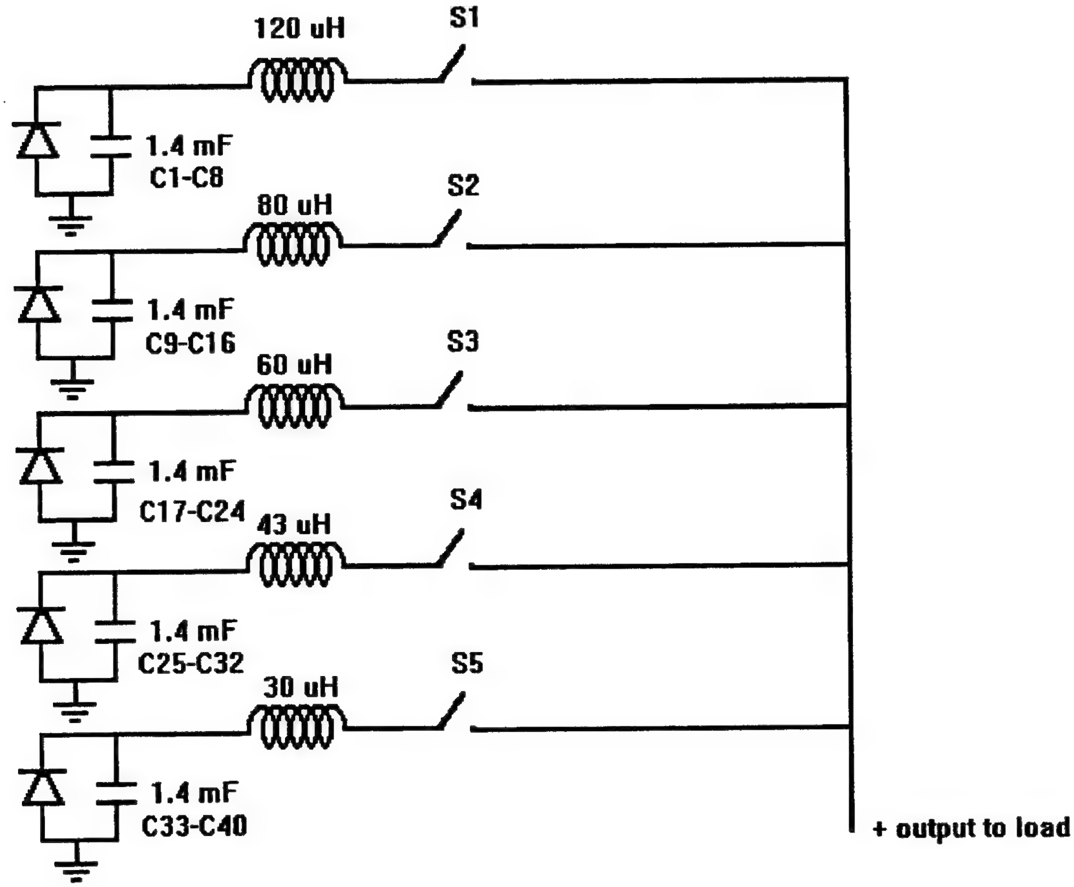
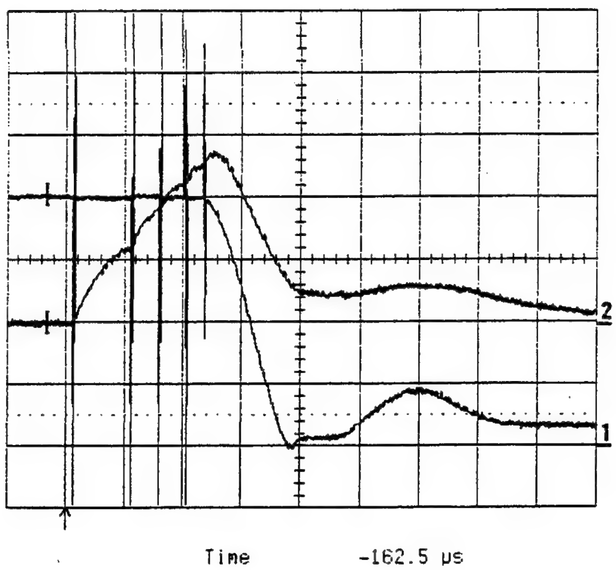


Figure 1. Circuit diagram of a 2-MJ pulse forming network in the ARL mobile pulser system used for electric gun research.

for capacitor voltage reversal protection, and they effectively extend the life expectancy of the PFN capacitors by shunting the capacitors during voltage reversal. The feature of 10 independently triggerable submodules with adjustable time delay provides the pulsed output versatility required for several electric gun research programs of interest to the U.S. Army. Experimental and simulated PFN output profiles for a 2-MJ PFN modulator are shown in the data plots of Figures 2–5.

The PFN pulse shaping inductors are manufactured by Trench Electric, and individual units range from 30 μH to 120 μH of inductance. Each inductor is electrically tested prior to insertion in the power supply up to an electric potential of 132 kV. This procedure ensures proper pulsed power operation once the inductor is installed and exercised in an experimental program. International Rectifiers, Marcum Onterio, Canada, produces the power rectifiers used in the PFN, which are model no. C03-1488.



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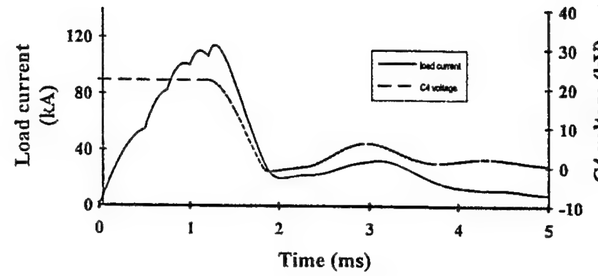
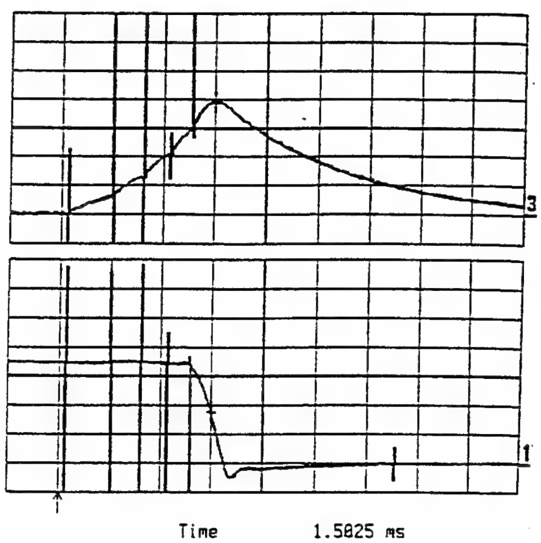


(b)

Figure 2. Experimental (a) and simulated (b) output load current and C25-32 voltage from cap bank four of the 2-MJ PFN submodule. Both data plots are with a 120-m load resistor and an initial capacitor voltage of 22 kV. Closing switch times are set at 0, 0.5, 0.75, 1.0, and 1.2 ms. Experimental current has a peak value of 112 kA at 1.25 ms.



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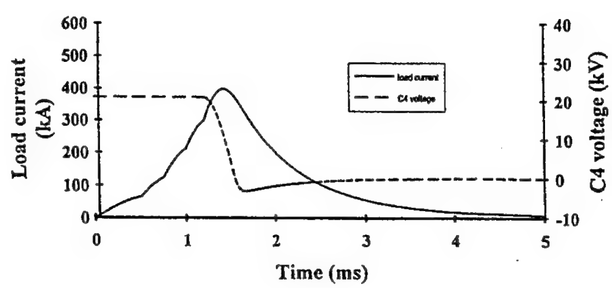

(b)

Figure 3. Experimental (a) and simulated (b) output load current and C25-32 voltage from the 2-MJ submodule during fault analysis. The load resistance for the PFN is a short circuit (4.2-m load). Initial capacitor voltage is 21 kV and switch closing times are 0, 0.5, 0.75, 1.0, and 1.2 ms. Experimental current has a peak value of 393 kA at 1.3 ms.

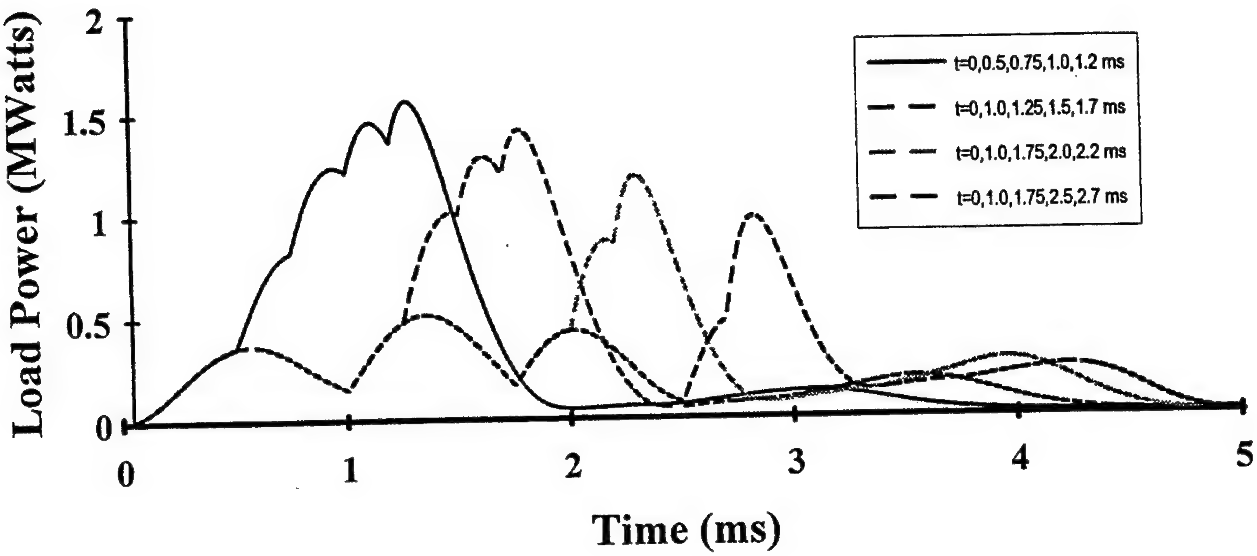

Figure 4. Demonstration of versatile output power waveforms through circuit simulations of a 2-MJ modulator into a 120-mΩ load having varied closing switch times. The closing times for the switches are indicated by the plot legend.

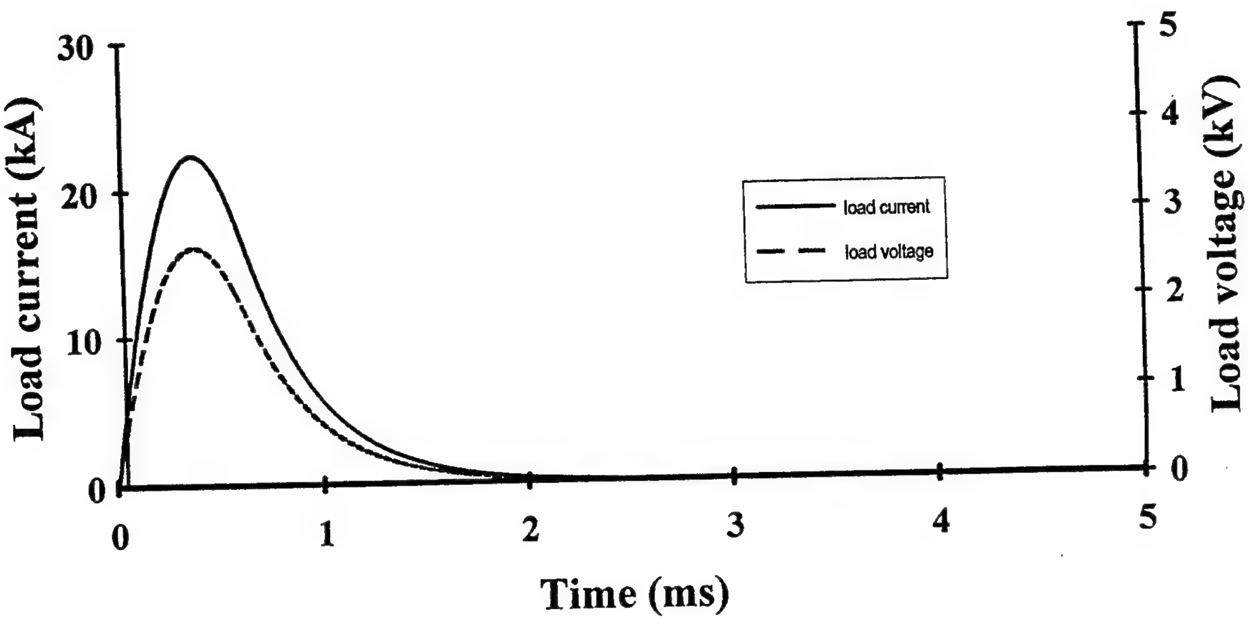

Figure 5. Simulated output current and voltage from one capacitor bank (bank three with 60-μH series inductance) of a 2-MJ modulator into a 120-mΩ load showing a pulse period of 1 ms.

The main function of the rectifiers is capacitor voltage reversal protection. The rectifiers are high-power silicon pn diodes having a reverse breakdown voltage rating of 15 kV and maximum forward current rating of 60 kA (8-ms pulse duration). Closing switches are manufactured by Physics International, CA, and are rated for 280 kA of peak pulsed current. The trigger generator that drives the sparkgap and begins the main current flow from the PFN is the Physics International model TG-75.

1.2 Control System. The control system provides remote operator control and monitoring functions for the 4-MJ pulser and prime power generators. The system was designed and fabricated by Vitronics Inc., under contract no. DAAL01-92-C-0265 managed by the U.S. Army Research Laboratory (ARL). As with the PFN design, system requirements for the 4-MJ control system were produced jointly by the Weapons Technology Directorate and the Physical Sciences Directorate (formerly Electronics and Power Sources) of the ARL. The main components of the control system are the trigger generator power supply or signal generator, capacitor charging control system, sequence-fault system, remote control, and power supply hardware.

The control system consists of an Interface Technology model RS-670 40-MHz digital signal generator, digital voltmeter displays for capacitor voltages, high voltage power supply control circuits, spark-gap switch trigger generators, safety relay control functions, and emergency circuits for experimental abort situations. The RS-670 signal generator provides trigger signals which are converted to optical signals and transmitted to the PFN sparkgap switches. The word generator has a maximum of 64 output channels and is capable of operating at data rates of up to 40 MHz with time variant digital output. The generator features a menu driven format in which operator interface is provided through a cathode-ray tube (CRT). Remote programming of the generator is possible through an optional IEEE-488 and RS-232 ports.

The capacitor charge system makes use of voltage-to-frequency converters and fiber optic signal transmission for voltage monitoring of the PFN capacitors. Hewlett Packard model HFBR-1402 optical transmitters and ADVF32KN voltage to frequency converters are the main components used in capacitor voltage to frequency converter circuits.

The system controller, see Figure 6, with hardware as mentioned is arranged in a standard 19-in equipment rack that is interconnected to the PFN through multimode fiberoptic cables. Color video

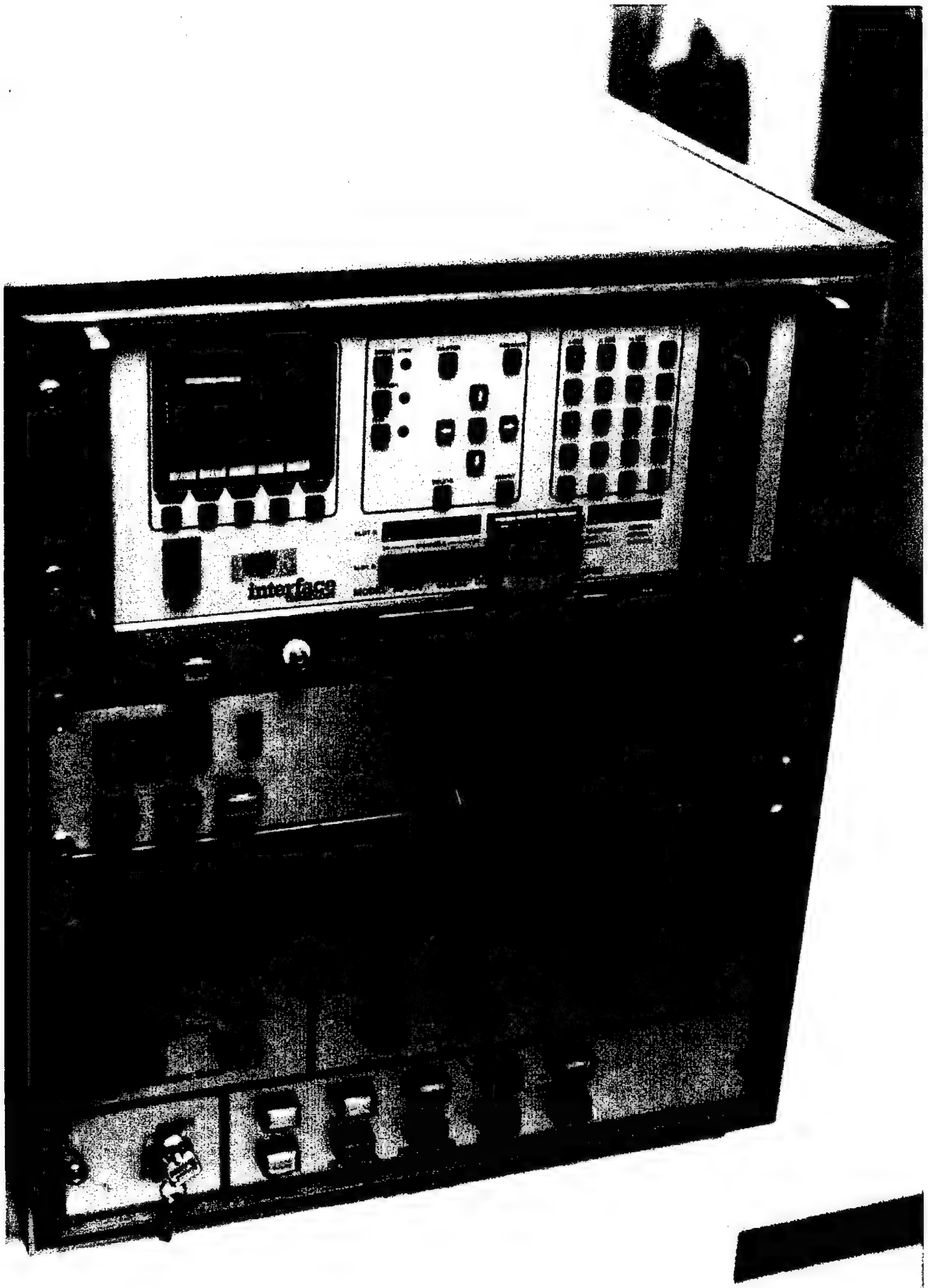

Figure 6. Control system for the 4-MJ mobile pulser system.

cameras and monitors are an integral part of the control system and were included to aid in confirming system safety status. The video cameras also are used for diagnostic purposes in the event of a component or system failure during an electrical discharge event. Schematic diagrams of the system are provided in the Appendix. They include the system diagram, the voltage to frequency converters, modulators, local meter panel, relay board, the disconnect assembly, and the resistive test load.

2. SUMMARY

A 4-MJ mobile pulsed power system has been designed, fabricated, and tested under the technical and managerial supervision of ARL for the purpose of electric gun propulsion research. Demonstration tests documented in this report have shown the system to be versatile in terms of output power pulse shaping, which is due to the multi-PFN and switch aspect of the power system. High energy capacitors, pulsed shaping inductors, and high voltage rectifiers are essential power components that have been incorporated into the PFN, which is controlled by a remote control system based on an Interface Technology digital signal generator and fiber optic interconnections.

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APPENDIX:

SCHEMATIC DIAGRAMS

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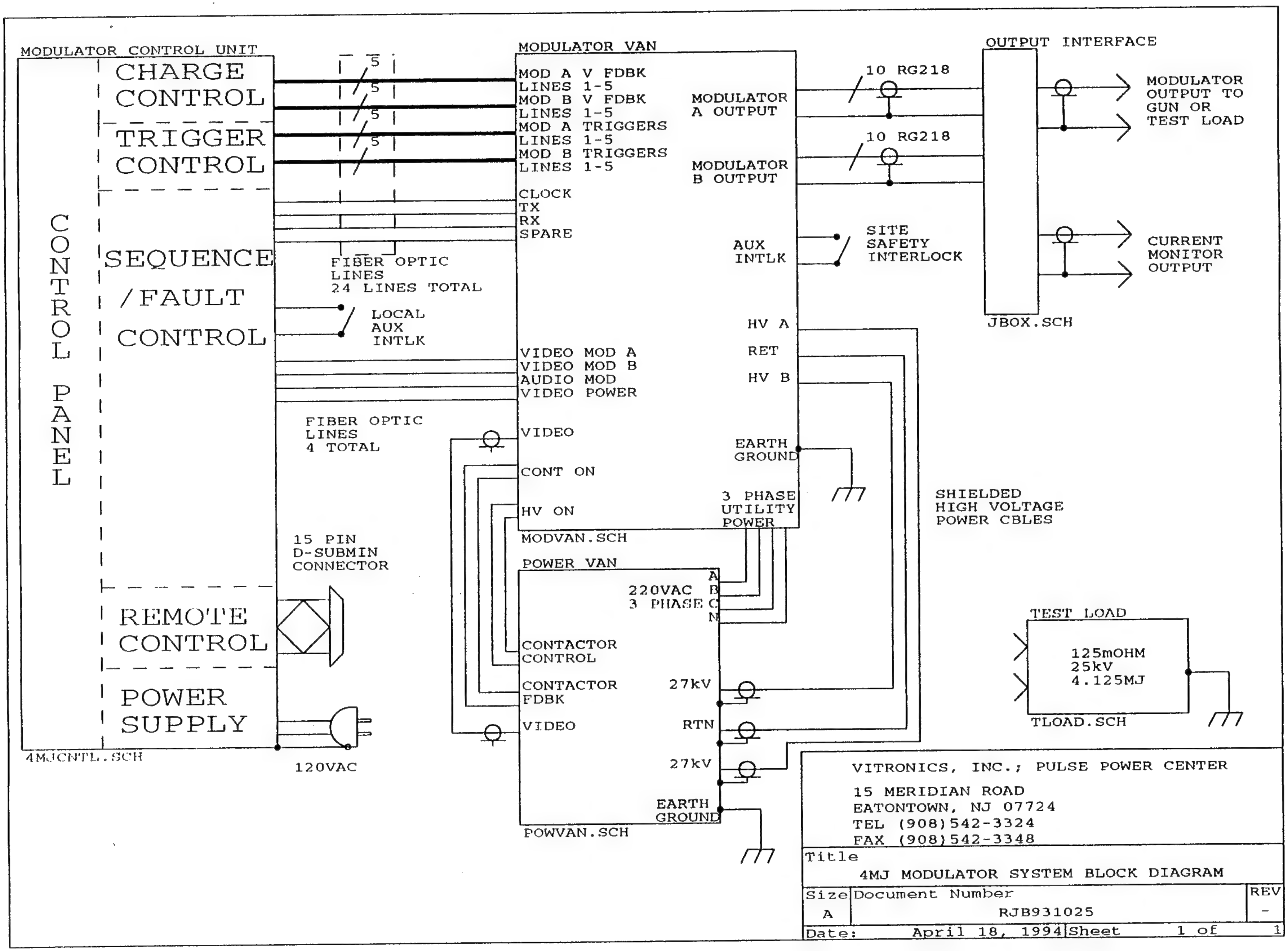
MODULATOR CONTROL UNIT
CHARGE CONTROL
TRIGGER CONTROL
SEQUENCE /FAULT CONTROL
REMOTE CONTROL
POWER SUPPLY
CONTROL PANEL
4MJCNTL.SCH
5
FIBER OPTIC LINES 24 LINES TOTAL
LOCAL AUX INTLK
FIBER OPTIC LINES 4 TOTAL
15 PIN D-SUBMIN CONNECTOR
120VAC
MODULATOR VAN
MOD A V FDBK LINES 1-5
MOD B V FDBK LINES 1-5
MOD A TRIGGERS LINES 1-5
MOD B TRIGGERS LINES 1-5
CLOCK
TX
RX
SPARE
VIDEO MOD A
VIDEO MOD B
AUDIO MOD
VIDEO POWER
VIDEO
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MODULATOR B OUTPUT
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RET
HV B
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3 PHASE UTILITY POWER
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10 RG218
SITE SAFETY INTERLOCK
OUTPUT INTERFACE
JBOX.SCH
MODULATOR OUTPUT TO GUN OR TEST LOAD
CURRENT MONITOR OUTPUT
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C
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25kV
4.125MJ
TLOAD.SCH
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15 MERIDIAN ROAD
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FAX (908)542-3348
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A
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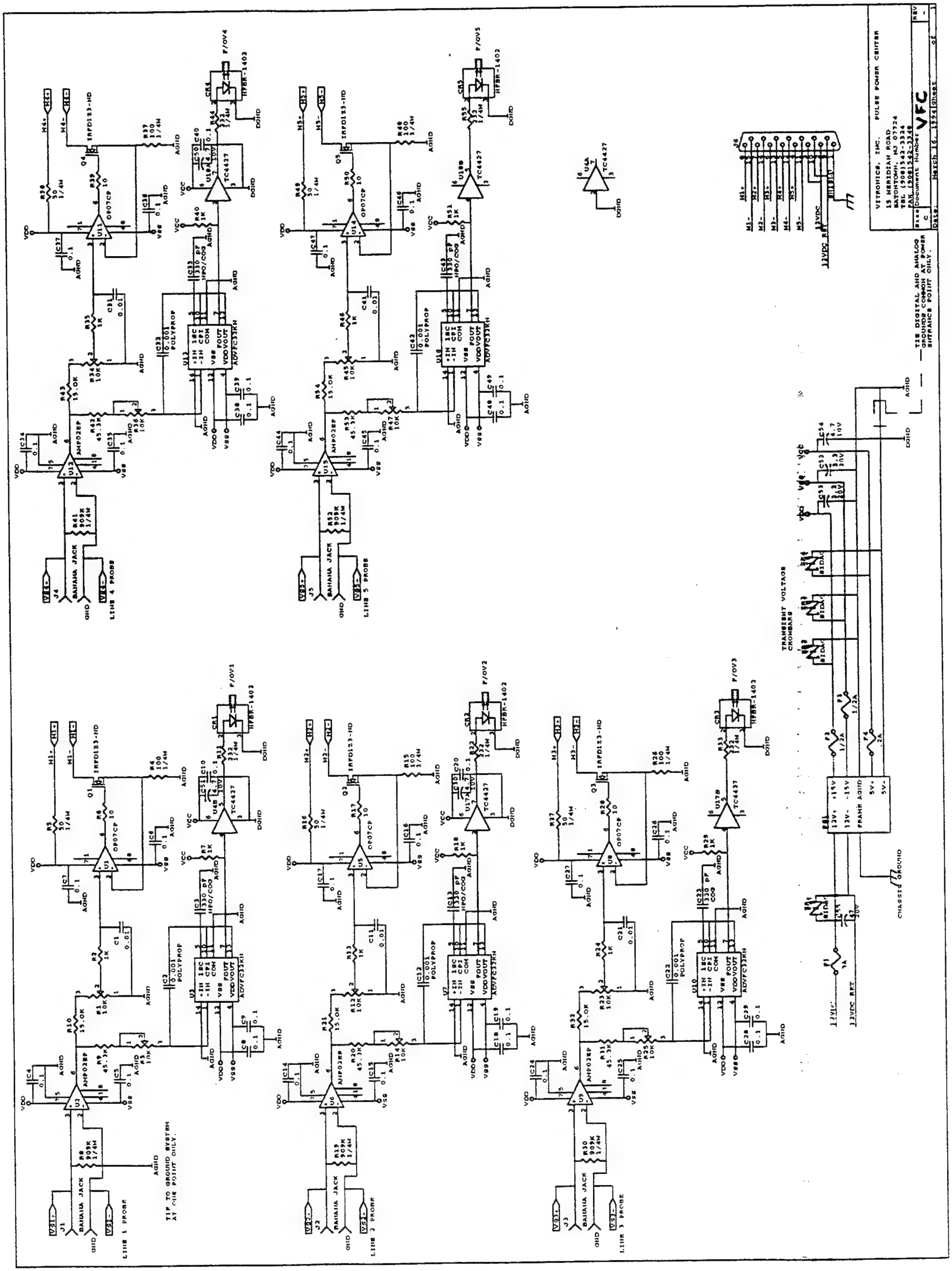
Date: April 18, 1994
Sheet 1 of 1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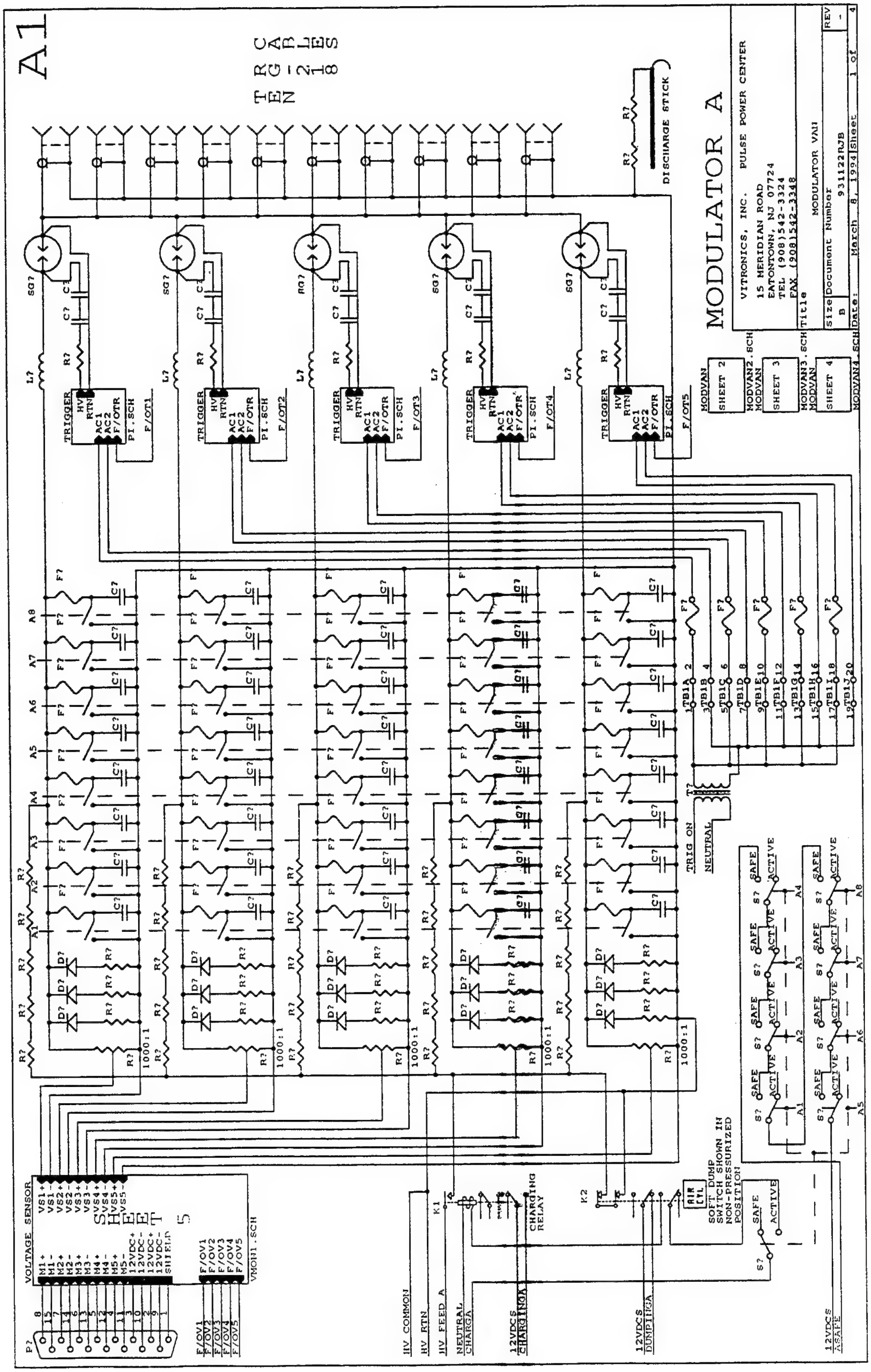
A1
TEN RG-218 CABLES
DISCHARGE STICK
MODULATOR A
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EATONTOWN, NJ 07724
TEL (908)542-3324
FAX (908)542-3348
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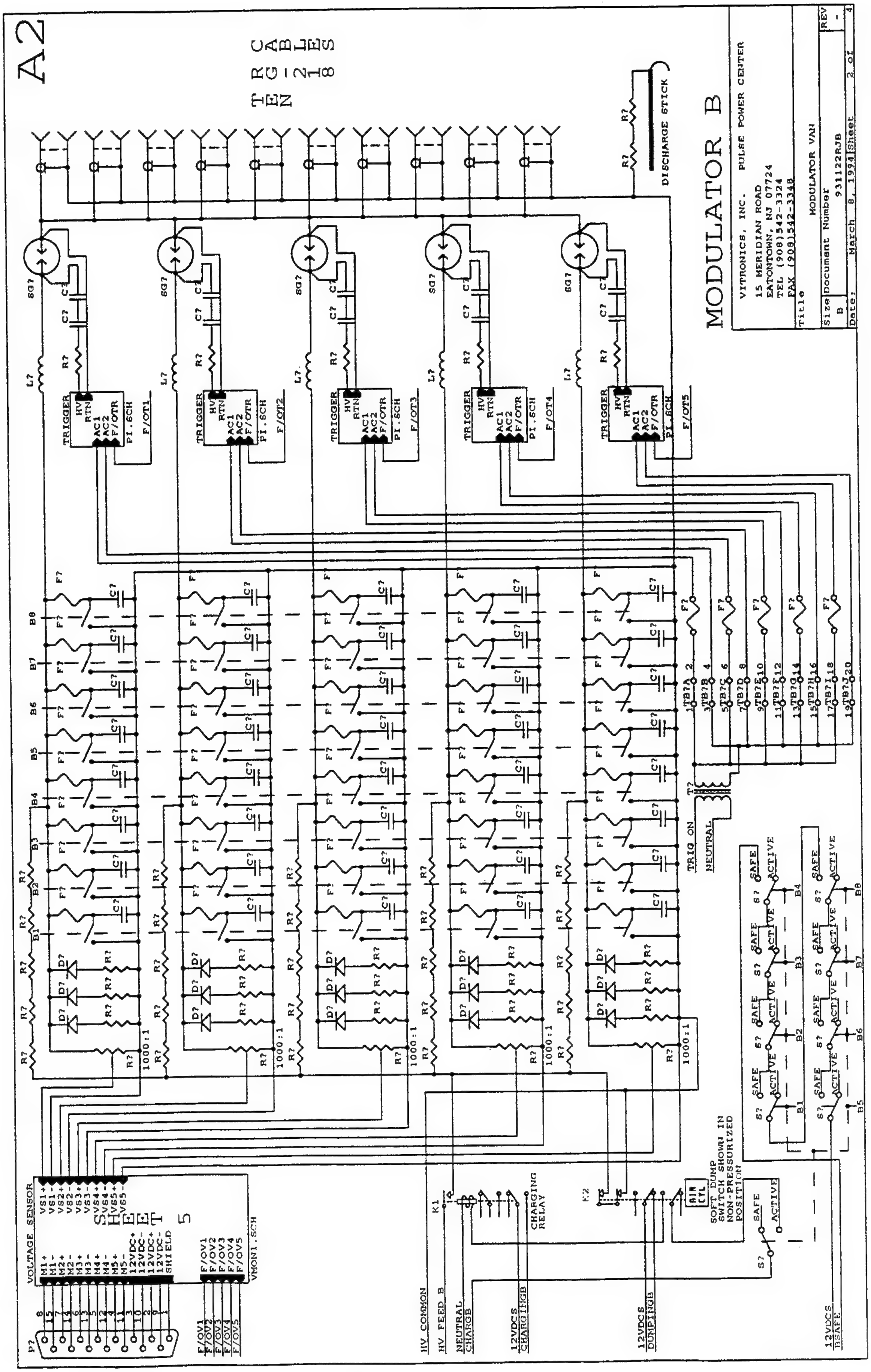
MODULATOR VAN
Size B
Document Number 931122RJB
REV -
Date: March 8, 1994
Sheet 1 of 4
VOLTAGE SENSOR
SHEET 5
VMON1.SCH
TRIGGER
PI.SCH
MODVAN SHEET 2 MODVAN2.SCH
MODVAN SHEET 3 MODVAN3.SCH
MODVAN SHEET 4 MODVAN4.SCH
TRIG ON
NEUTRAL
HV COMMON
HV RTN
HV FEED A
NEUTRAL CHARGA
12VDCS CHARGINGA
CHARGING RELAY
12VDCS DUMPINGA
SOFT DUMP SWITCH SHOWN IN NON-PRESSURIZED POSITION
AIR CYL
12VDCS ASAFE
SAFE
ACTIVE


A2
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Document Number 931122RJB
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Sheet 2 of 4
TRIGGER
VOLTAGE SENSOR
SHEET 5
VMONI.SCH
CHARGING RELAY
SOFT DUMP SWITCH SHOWN IN NON-PRESSURIZED POSITION
TRIG ON
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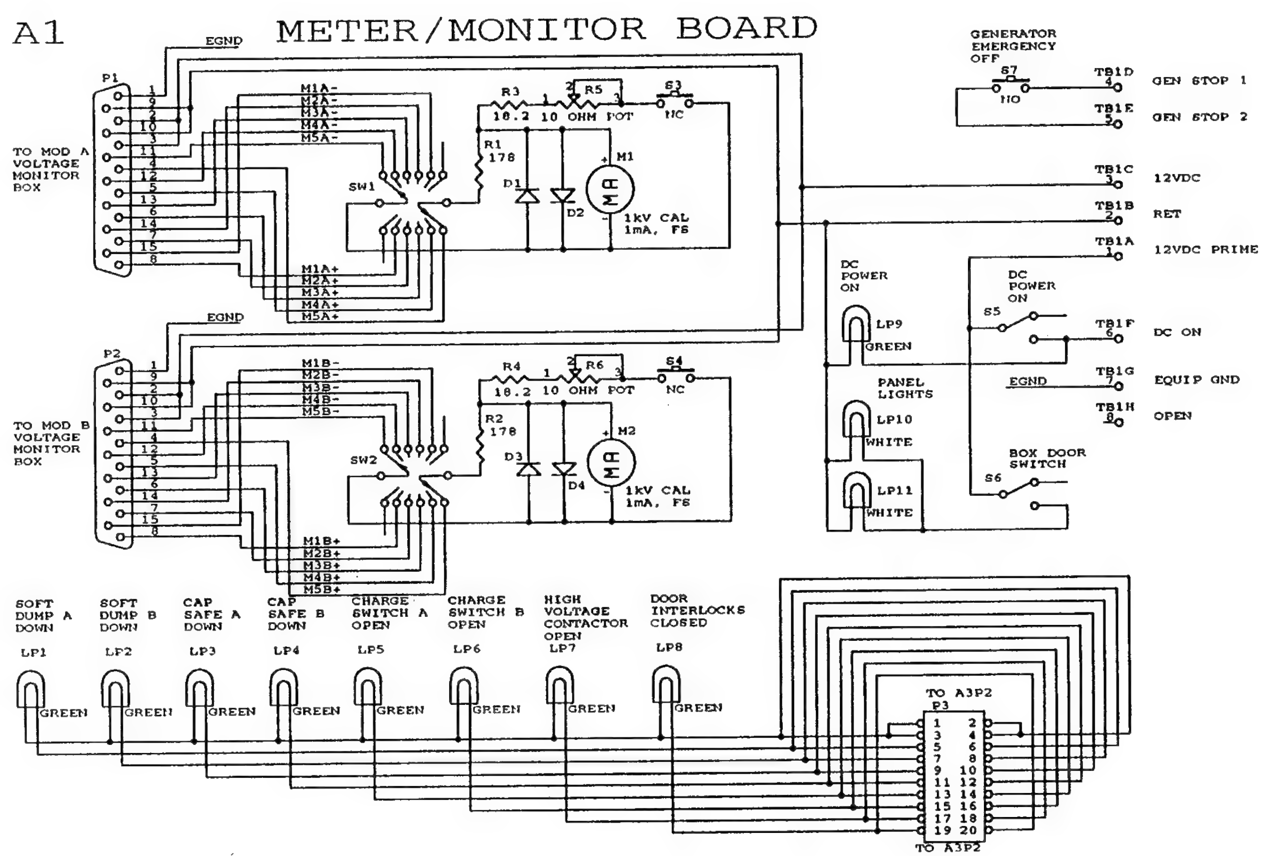
ACTIVE



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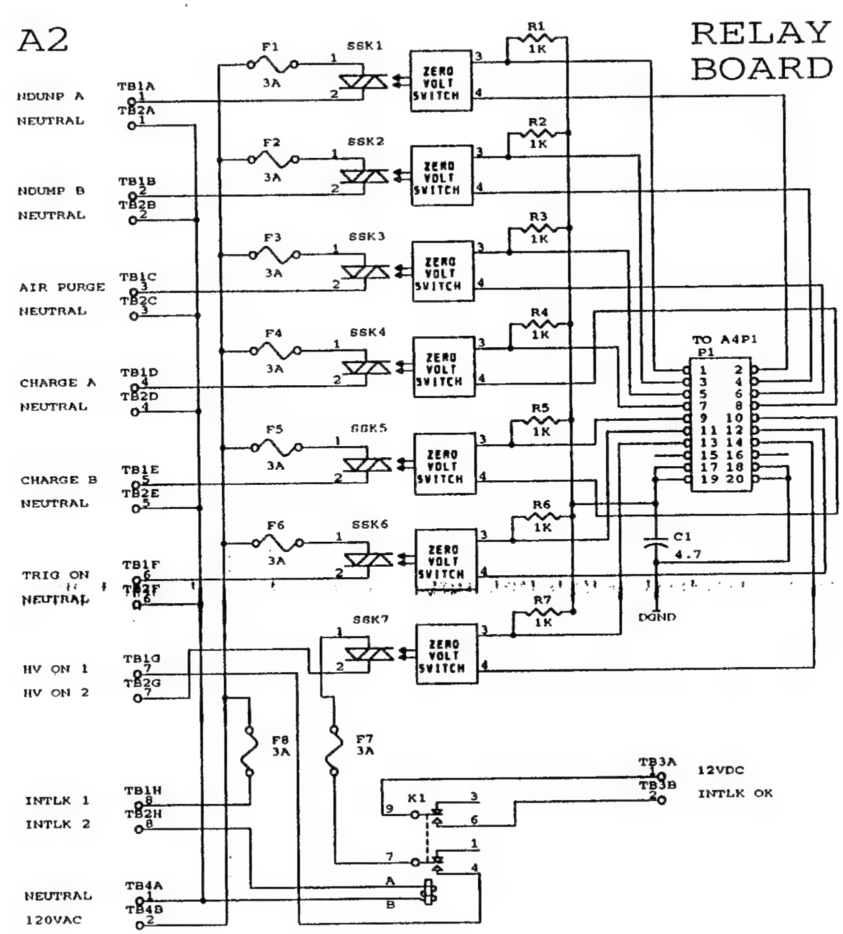

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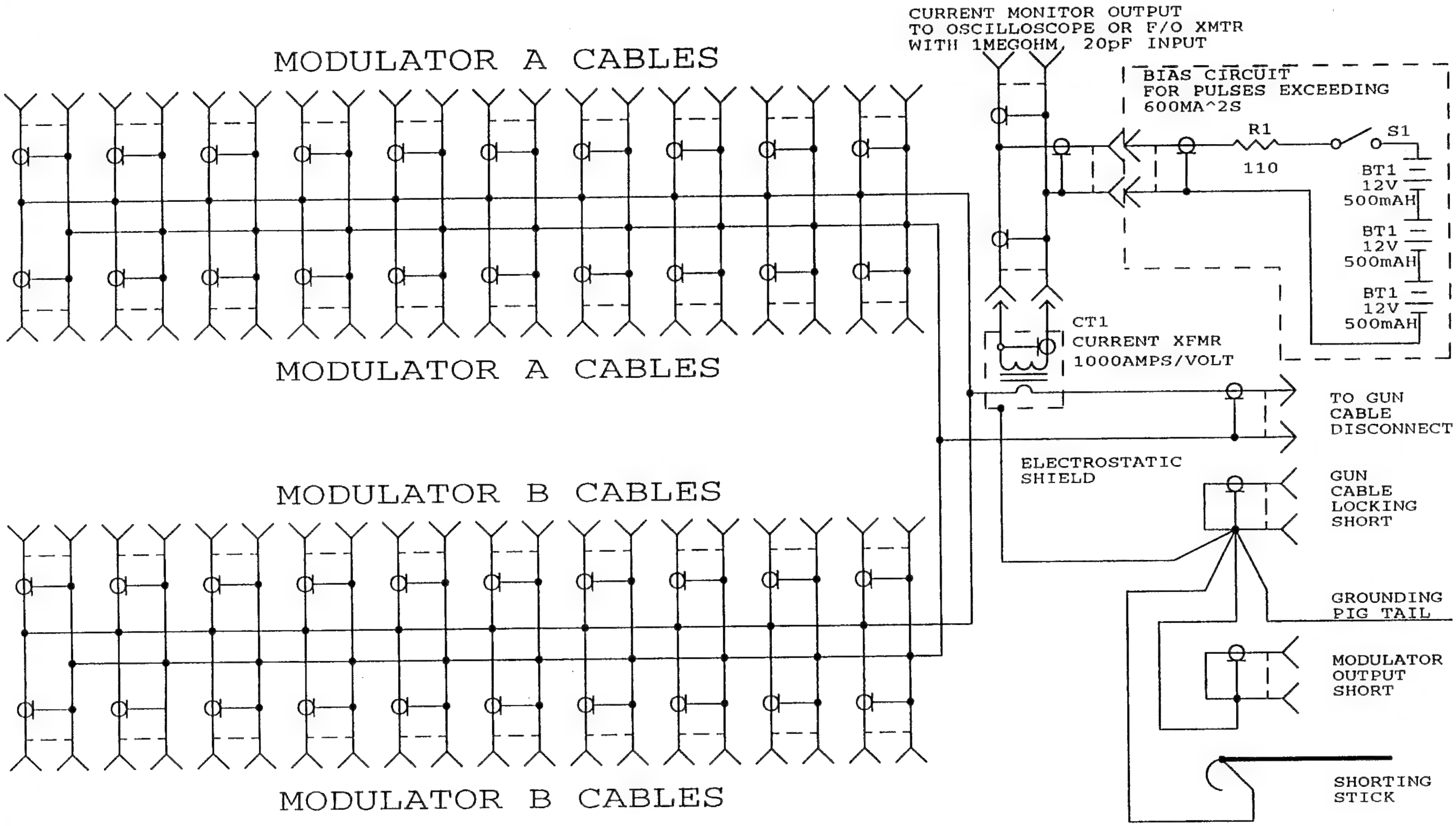

NOTE: MODULATOR A AND B CABLES ARE RG218 TYPE.
40 CABLES TOTAL CAPABILITY, 20 INSTALLED.

VITRONICS, INC. PULSE POWER CENTER 15 MERIDIAN ROAD EATONTOWN, NJ 07724 TEL (908)542-3324 FAX (908)542-3348		
Title MODULATOR OUTPUT DISCONNECT ASSEMBLY		
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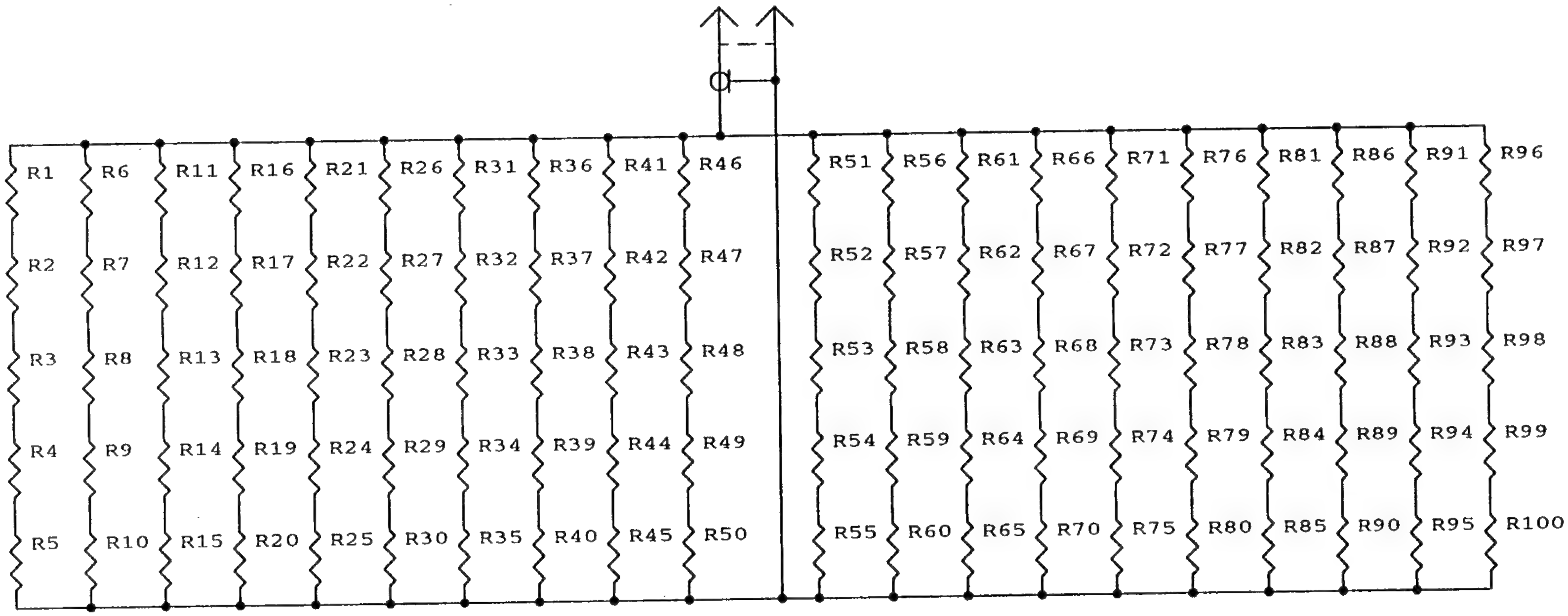

TOTAL LOAD CAPABILITY: 62.5 mOHM
25 kV
8.25 MJ

LOAD WITH R1-R50 INSTALLED: 125 mOHM
25 kV
4.125kJ

NOTE: 1) R1 THROUGH R100 ARE 0.25 OHM, 82.5kJ WASHER TYPE RESISTORS.
2) COPPER SHEET WASHERS, .010" THICK GO BETWEEN EACH RESISTOR.

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EATONTOWN, NJ 07724
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